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IMPACT OF DEVELOPMENT ON STREAM FLOWS

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IMPACT OF DEVELOPMENT ON STREAM FLOWS

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PREFACE

This study was initiated to study the potential impacts of second-home and resort community development in forested watersheds of northern Arizona. The project was sponsored by the Eisenhower Consortium for Western Environmental Forestry Research as one of a series of studies concerned with the use and conservation of forest lands in the Rocky Mountain area. I am grateful for the Eisenhower Consortium sponsorship and for the assistance received from U. S. Forest Service personnel of the Rocky Mountain Forest and Range Experiment Station.

In particular, I would like to thank Dr. James J. Rodgers (Hydrologist, U.S.F.S. - Tempe) for use of his developing computer program which made the approach chosen in this study possible. I would also like to give particular thanks to Dr. Malchus Baker (Hydrologist, U.S.F.S. - Flagstaff) for spending the time necessary to show me how to make use of the extensive data available for the Beaver Creek Project and for suggesting the Woods Canyon area within it as my project focus.

The assistance of William B. Vandivere (graduate student, College of Natural and Renewable Resources, U of A, Tucson) who spent much of last summer doing the basic foundation studies for this project is also acknowledged. His insights and research helped considerably in narrowing the field of variables to be considered.

More locally, I would also like to thank the staff of the College of Engineering and Technology for their indispensable help in typing, correcting and editing this and the other reports resultant from this study. Especially, Mrs. Pat Almlof, secretary to the Dean of the College of Engineering and Technology, for always finding a way to get the job done and done right despite the pressures of other responsibilities.

Finally, I wish to acknowledge the support and patience of my wife, Cathy and daughter, Kimberly, who gave up my company for much of last summer.

ABSTRACT

This report presents the findings of a study intended to identify the long range effects of development upon stream flow. The study has attempted to identify the hydrologic parameters most effected by the development of rural forested watersheds into second-home and resort type communities. Once identified, the parameters selected were changed from their original values to values which reflect a variety of development levels ranging from undistrubed watershed up through complete suburban development with housing densities as high as one house per quarter acre. A computer simulation was then used to predict the stream flow for each level of development. The results indicate that such development increases significantly the surface runoff from the watershed.

CONTENTS

Chapter		Page
	PREFACE	
	ABSTRACT	
I	INTRODUCTION	1
II	LITERATURE SEARCH	5
	Historical Perspective	5
	Urbanization	5
	Second-Home Development	9
III	THE WOODS CANYON STUDY AREA	11
	Partitioning Woods Canyon	13
	Soil Types Within Woods Canyon	15
IV	HYDROLOGIC BACKGROUND	21
	Hydrologic Variables	21
	Interception	21
	Detention and Depression Storage	23
	Evaporation and Transpiration	24
	Infiltration	25
	Percolation	26
	Runnoff	26
V	HYDROLOGIC SIMULATION	28
	ECOWAT	29
	Canopy Water Balance Component	29
	Snowpack Component	30
	Litter Water Balance Component	30
	Surface Water Balance Component	30
	Soil Water Balance Component	30
	Plant Water Relations Component	31
	ECOWAT Simulation History	31
	Simulated Development	31
VI	RESULTS AND CONCLUSIONS	35
	Overview	35
	Calibration and Simulation	36
	Conclusions and Recommendations	39
	APPENDIX A	41
	APPENDIX B	42
	REFERENCES	49

LIST OF TABLES AND FIGURES

Table		Page
1	Hydrologic Response Unit (HRU) Data	15
2	Woods Canyon Soil Survey	17
3	Soil Types by Percent for Woods Canyon	18
4	Ground Water Parameters for Woods Canyon Soil Types	19
5	Average Soil Parameters for Woods Canyon	20
6	Major Continuous Stream Flow Simulation Models	28
7	Development Levels	32
8	Values of Hydrologic Variables for Various Levels of Development	34
9	Calibration Results - Average Annual Flow	36
10	Calibration Results - Peak Month	37
11	Average Annual Flow and Peak Month vs. Development Level	38

Figure		
1	Beaver Creek Watershed Locator Map	12
2	Woods Canyon Within Beaver Creek	12
3	Hydrologic Response Units Within Woods Canyon (HRUs)	14
4	Woods Canyon Soil Map	16

IMPACT OF DEVELOPMENT ON STREAM FLOWS

Chapter I

Introduction

In the arid regions of the southwest and west forests provide significant quantities of the water for the life style chosen by its human inhabitants. The forests not only provide the "catchment" for renewing surface and ground water resources but also have a significant role in regulating the supply of water to these sources. It is essential, therefore, to the forest manager as well as the city planner to come to a qualitative as well as quantitative understanding of the impacts of development on stream flows and how the regulating effect of the watershed on stream flow is influenced by changes in land use.

The forest manager is often faced with decisions concerning the development of recreational areas, with all their appurtenant structures. Will these proposed changes effect the "productivity" of the watersheds? Will the total quantity of stream runoff be changed? Will its distribution through time be changed? If so, how much? And, who is responsible, should a change of the watershed influence the value of a downstream water-right?

Second-home and resort town developments have impacts upon almost every phase of the hydrologic cycle. The changes may impact the distribution of stream discharge through time, as well as the discharge in total. Understanding how the net effect of these changes on the rural forested watersheds influences the streams is of great importance for the planning decisions made both within the forest managers office and outside it. Planning and development decisions must often balance the conflicting needs of the downstream users, environmentalists endeavoring to preserve natural balances, and those who desire to live in or develop second-home and resort communities.

Some of the impacts of development upon previously undeveloped watersheds may be listed briefly as:

a) Changes in the runoff, evapotranspiration, and infiltration character of a watershed due to changes in land use or ground cover caused by;

- Buildings, parking lots and streets.
- Landscaping modifications such as the clearing of trees for ski runs, parks and pastures.

b) Changes in the use and distribution of water in service to man, which may affect the flows in natural streams.

- Surface water rights may have points of diversion or pattern of use changed; return flows will subsequently be altered in space and time.
- Ground waters may be pumped and reapplied to the ground by septic tank leach lines in different geologic strata thereby, effecting a transfer from one stream to another.
- New technologies (e.g., land application of waste water) may alter water usage patterns.

All of these effects (and probably others) may have noticeable impacts upon quantities of flow as they are typically measured. Individual effects may, however, be impossible to measure due to the complexity and inherent short range variability of the hydrologic system. The aggregate effect may also be disguised to some extent by the natural fluctuations of streams from year to year.

Many small communities of second-homes and resort facilities are experiencing growth of a year round nature far beyond the increase in second-home building and hotel/motel accommodations. Often multiplier effects of recreational development create year-round communities of service related people.

This is due in part to the increase per capita wealth of tourists, which results in growing job markets, and to the significant fraction of people who are willing to "suffer" the feast or famine economic situation of seasonal tourism for the sake of living in choice environments all year. How might the modifications to the watershed resultant from development coupled with the significant seasonal imbalance of use affect water availability in the off season months?

Planning officials at various levels have to deal with these issues in hopes of providing sound guidance and/or bases for rational decision making. In a recent survey of municipal planners one of the currently unsatisfied informational needs of planners was reported as being the relationship between planning decisions, impacts on the water resources of the region, and all the resultant feedback effects. The complexity of the hydrologic cycle, however, and the all but impossible task of modeling it adequately in a changing environment has prohibited researchers from answering this question in the form asked. The time required for the various effects of development on runoff to be noticed varies dramatically. Some effects impact upon the peak runoff from storms, while others may affect only total seasonal quantities, while still others have impacts on both.

No effort will be made in this study to measure changes in transient peak flows from storms and other short-lived impacts related to development. Attempts will be made to identify the long range aggregate effect. The aggregate effects should be evident in the larger measurements of total yearly flow, total peak season flow and total non-peak flow. These aggregate effects if present will be of greater value for long range planning decisions since the details of anticipated developments are generally unavailable for evaluations of the individual short range effects. Gross trends can however, provide insights useful for current decisions.

A hydrologic simulation model was ultimately chosen to help answer of the above questions. This course was chosen for various reasons. First, among them was the inability of the researchers to find a suitable site for a

longitudinal study within the constraints of the study. A relatively small watershed would have been needed with a continuous flow record throughout a significant period of development which affected a large fraction of the land area. This did not seem to be available.

The second reason hydrologic simulation was finally chosen was the availability of a simulation model, designed as a forest management tool, within the U.S. Forest Service. This developing model (ECOWAT developed by Dr. Jim Rodgers USFS Tempe) is suitable for studying long term effects on small watersheds.

The third reason relates to the second. The Beaver Creek project is an on-going forest management project run by the Forest Service. It has a significant data base for some relatively small watersheds in areas similiar to those being developed in Northern Arizona as second-home and recreational sites.

Chapter II

Literature Search

Historical Perspective: Historically, as the pace of environmental manipulation has accelerated, planners and watershed managers have requested quantitative and qualitative assessments of the effects of changes in land use upon streamflow. The increasingly diverse nature of these manipulations has necessitated equally diverse investigation, especially in this era of multiple resource optimization techniques. Due to differences in hydrometeorological regimes, it is often impractical to extrapolate regionally derived results. However, definite trends are evident in the effects of timber harvesting, mining, agriculture, and urbanization upon certain aspects of streamflow.

The last decade has witnessed a proliferation of studies dealing with the short range effects of urbanization on previously undeveloped rural watersheds. The theme in this report is somewhat different from to the majority of prior efforts undertaken on this topic. Here, as was previously noted, the focus will be upon the effect of second home construction upon streamflow in the aggregate, i.e., monthly or seasonly streamflow volumes.

In the following section a background discussion is offered which briefly identifies previous attempts at quantifying the hydrologic response of urbanizing watersheds. This is succeeded by a similar survey of literature accrued from the specific investigation of second-home development as they related to watershed modifications.

Urbanization: Concerning the impact of human settlement on previously undeveloped rural watershed, the bulk of the available literature has directed its attention towards urbanization. Although the breadth of this topic is extensive, research bias as well as funding has favored study of the developmental acceleration in areas situated on the periphery of expanding metropolitan areas.

Inquiry into the hydrologic characteristics of urbanizing watersheds has concentrated on the alteration of: shape and timing of runoff hydrographs; flood magnitudes for events of varying recurrence intervals; and, quantitative evaluation of runoff volume and stream sediment loading.

In a California study, McBride (1976) observed that urbanization of a watershed in the Berkeley Hills region produced values of peak daily streamflow, ten times those of a similar non-urbanized watershed. Another California investigation (James, 1965) contrasted runoff volumes from a watershed in both its pre-urban and urbanized forms. It was estimated from streamflow records that runoff volume from the completely urbanized watershed was 2.3 times that produced by the same basin in its rural condition.

For a topographically dissimilar area in North Flordia, Turner, et. al. (1975) found that urbanization, defined as residential-commercial land use, of a watershed near Lake Jackson increased peak stream discharge and total stream discharge volume.

A review of publications dealing with the effects of urbanization on floods of varying recurrences intervals was compiled by Hollis (1975). Conclusions projected from empirical studies by Leopold (1968) showed that paving of less than 5% of the drainage basin area had a negligible effect on floods with return periods of one year or more, while paving of 30% of the watershed may double observed discharge resulting from a 100-year flood. In addition, Herr (North Carolina) was cited as having inferred that a flood with a recurrence interval greater than 150 years is essentially unaffected by urbanization.

The estimation of land use characteristics for purposes of hydrologic modeling was examined in a recent Maryland study (Gluck & McCuen, 1975). In researching suburban development within the expanding Washington, .D C. metropolitan area, the investigators assembled non-linear land use prediction equations based upon statistical relationships between population density,

employment density, housing density, distance from the central business district, and percentage of impervious area. The resultant equations modeled the following parameters: 1) impervious area, 2) residential housing, 3) commercial, 4) parking, 5) streets, 6) agriculture, 7) grassland, and 8) forest. Obviously, the equations are restricted in application to surburban localities with access to a demographic data base, a requirement not likely to be attainable in second home developmental situations.

Wherever construction activities exist, erosion and sedimentation become prime concerns of watershed managers. Recent advances in soil conservation practice nothwithstanding, the deposition of sediment by storm runoff has implications for any form of urbanization.

Due to energy requirements placed upon a stream channel functioning as a medium for sediment transport, the stream entity is forced to modify its hydraulic geometry. As an example, an Ohio stream channel was enlarged 2.8 times resulting from a change in watershed imperviousness of 30% (Apmann, 1974). This increase in the impervious area produced an estimated 40,000 tons of sediment per year over a 31-mile channel reach.

In a pre-urbanized calibrated basin in England, Walling (1974) studied the effect of building construction on sediment yield. After one year of development affecting 25% of the watershed, sediment yield was found to have increased 5 to 10 fold.

The deleterious effects of road construction on sediment yield have been well documented (Reed, 1971, & others). Unstabilized embankments and shoulders unleash substantial quantities of sediment which ultimately reach the waterway. Rural unpaved roads such as would be prevalent in developing second-home communities may have significant impact on sedimentation in the affected river basin, considering the relatively small proportion of total impervious area they provide.

Studies involving the urbanization of previously dominant forested watersheds often necessitate consideration of more variable soil and topographic regimes than those customarily identified with low lying urban plains. Runoff from forested areas is reduced by increased interception, higher infiltration, decreased overland flow, increased soil moisture, and increased evapotranspiration. Consequently, urbanization of forested watersheds could be expected to result in major diversions of rainfall to the runoff phase due to adverse effects on the relevant hydrologic parameters.

An inquiry of this nature was made by Wooldridge (1967) on a small forested watershed near Seattle, Washington. Results demonstrated urbanization increased the proportion of rainfall manifesting itself as daily discharge approxi mately three fold: From 0.099 to 0.296 c.f.s. per inch of rainfall. In a similar study conducted in East Africa, Dagg and Pratt (1962) related runoff from the largest observed storms on a 31-acre forested watershed to less than 1% of measured precipitation. In contrast, runoff from a 32-acre contributing area dominated by a housing and administrative complex amounted to 36% of rainfall when subjected to these same hydrometerologic events.

An extensive study directed by the Northeastern Forest Experiment Station (Lull and Sopper, 1969) documented hydrologic response (annual ratios of stormflow to precipitation) and its seasonal variant of progressively urbanizing forested watersheds in the Southern New England region. The effect of urbanization was evaluated as a net reduction in evapotranspiration with runoff from paved surfaced assumed to enter directly into streamflow. Increases in the impervious area of 25, 50, and 75 percent resulted in annual increases in runoff of 15, 29, and 41 percent respectively. It was also found a measureable seasonal variation existed between forest and urban affected stormflows. A completely forested area produced 80% of its runoff during the dormant season (October through March) where as runoff for this same period from a heavily urbanized area (75% imperviousness) amounted to just 62% of total annual stormflow.

Additionally, Lull and Sopper, utilizing data from East Coast watersheds, attempted to gage the effect of urbanization on streamflow records. Regression analysis of actual annual runoff and predicted runoff, simulated through the use of a computer program (Black, 1967), indicated increasing stormflow, peak flow, and annual runoff for progressively urbanizing waterhsed. It should be noted, since it has relevance to the present study, that via regression technique annual ratios of streamflow to precipitation was evidently the most sensitive indicator to urbanization.

Although the tendencies outlined above are generally applicable, the authors do advise discretionary use of ad hoc correlations between urbanization and increased hydrologic response. They caution that increased peak discharges are dependent not only upon the aerial extent of urbanization, but on the spatial characteristics of the development with respect to the composite watershed. Parameter alteration affected by human habitation such as increase in the percentage of impervious surface or reduction in evapotranspiring area which may initially suggest augmented runoff volume may be subject to counter vailing influences such as ground water pumpage and/or transfer of locally occurring subsurface waters to different geologic strata thus reducing that segment of streamflow appearing as baseflow.

Second-Home Development: Owing to the apparent paucity of literature available on the subject of second-home development and the limited time allotted for search in the area, only two surveys were uncovered which were deemed relevant to the present study (Bond and Dunikowski, 1977, Hogan 1977). Since the reports discuss only the implications and projections of second-home development and their impact on water availability in Arizona and make no reference to the role development plays in determination of the hydrologic response of a watershed, their treatment herein will be principally restricted to socio-economic analysis.

The Bond report classifies a second-home as: 1) a permanent (some semipermanent) structure, 2) owned or leased (12 month basis), and 3) primarily functioning as a dwelling for recreational and leisure-time purposes. Hogan concluded from his survey of Arizona second-home residents that scenic, forested locations with relatively close proximity to permanent residences were most likely to be targeted for growth of the second-home variety.

It was also indicated in Hogan's study many who initially purchase a second-home for recreational purposes eventually plan to make it their permanent residence upon reaching retirement age. This practice will in all likelihood increase residential demand for addition or expansion of previously limited public and private facilities which inevitably arise when the median age level of the community rises. Golf courses, improved roads, shopping complexes, and hospitals and nursing homes are but a few of the diverse services which could be sought.

There are two conclusions incorporated in Bond's research which merit some attention from a hydrologic perspective. First, it was calculated that total water consumption by second-homes amounted to approximately two-tenths of one percent of state municipal and industrial usage. Although this seems of little consequence when viewed in isolation, its significance is heightened (at least in Arizona) since invariably residents tap the ground water system for their consumptive needs. As was pointed out earler, this practice could lead to depletion of the baseflow component of streamflow either directly on through transfer of treated wastewater or to other drainage systems.

Chapter III

The Woods Canyon Study Area

Within the Beaver Creek study area maintained by the U.S. Forest Service is the Woods Canyon area which was chosen for this study. There are four basic reasons why the Woods Canyon area was chosen:

1. Plausability of Development
2. Similarity to other Developed & Developing areas in the region
3. Data Availability
4. Forest Service interest in this Area

The Woods Canyon area has high accessability being located along the highway from Flagstaff to Phoenix (Interstate Highway 17). It is suitably located for vacation homes for the Phoenix area being somewhat closer and more rural than areas closer to Flagstaff. It is not, however, so far from Flagstaff that its remoteness would be a problem. It could even attract year round residents to some degree with a 25-30 minute commute to Flagstaff.

Other areas along I-17 in private ownership have experienced development similar to that which is to be simulated for the Woods Canyon area. Such areas as Munds Park and Mountain Air and Katchina Village have similar hydrologic and geographic characteristics and suggest the plausability of the development simulated.

For a project of the type approached in this study, data availability was a serious constraint. The Forest Service, however, has been collecting data on the Beaver Creek study area, which includes Woods Canyon, for many years. This data was gratiously made available to this study along with the suggestion that Woods Canyon would be a good choice considering both the goals of this study and the quality of the Woods Canyon data.

Figure 1 and 2 illustrates the Beaver Creek study area and Woods Canyon within it. Also illustrated are the proximaties to the major cities.

Figure 1: Beaver Creek Watershed Locator Map (U.S.F.S., 1977)

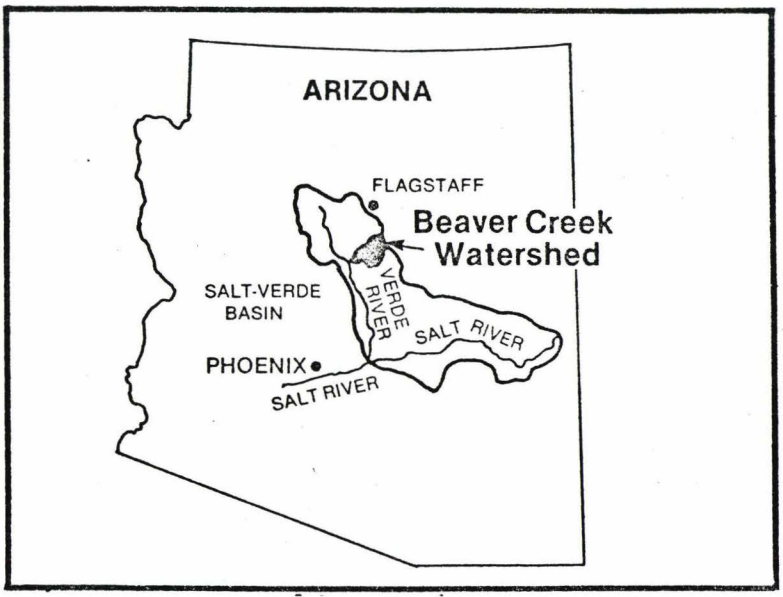
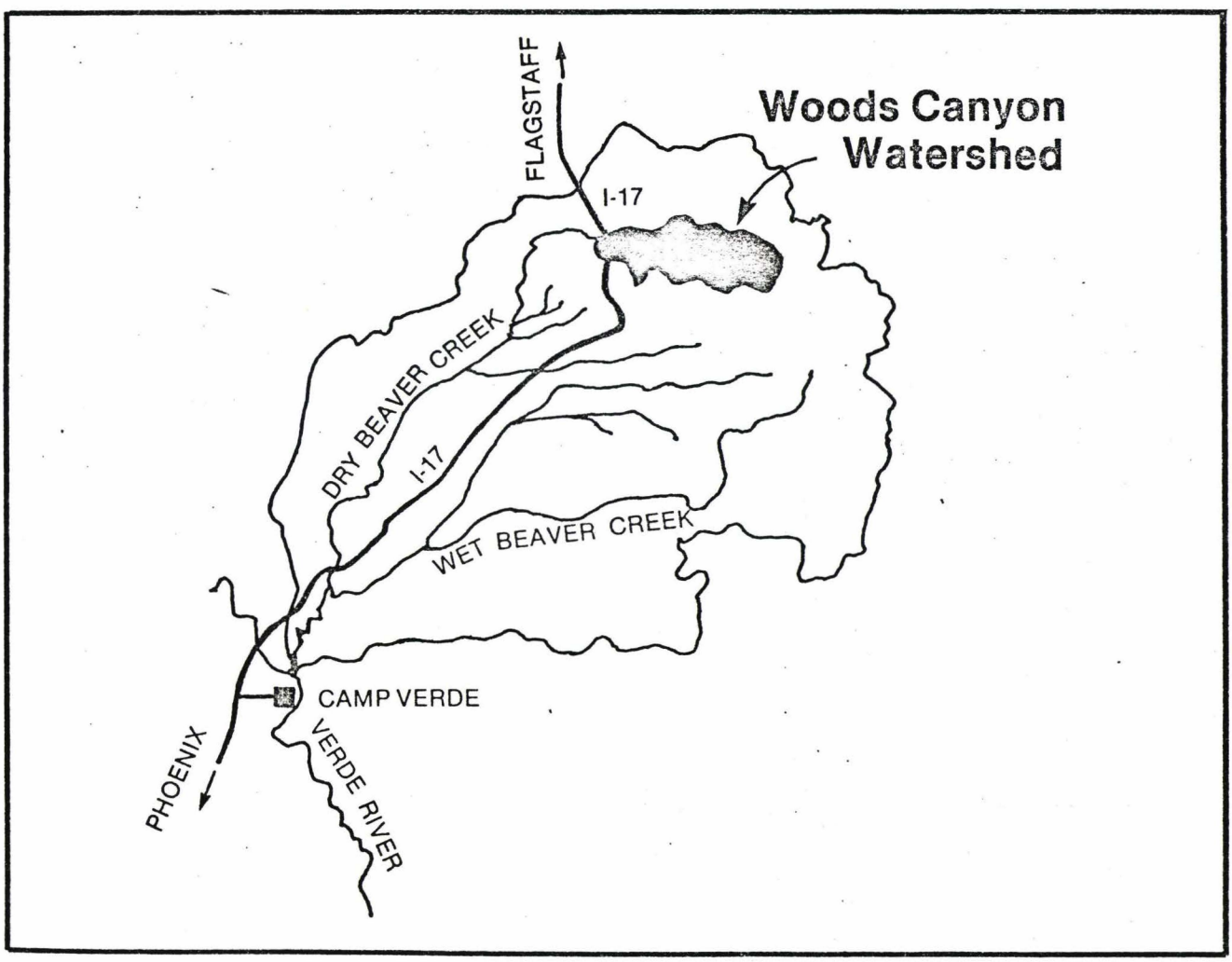


Figure 2: Woods Canyon Within Beaver Creek (U.S.F.S., 1977)



Partitioning Wood Canyon: Within the Woods Canyon area separate hydrologic response units were delineated. Although eight hydrologic response units (HRU) appeared initially to be the ideal number, from a purely hydrologic homogeneity standpont, the realities of computer time and system complexity resulted in a reduction to four. A variety of parameters were used to delineate the HRU's. Among those most important from a hydrologic point of view were, drainage, elevation, slope and aspect.

With only four HRUs, and considering the nature of the topography (low mountains and canyons), it was difficult to maintain consistent drainage patterns. The ideal pattern of identifiable local drainage areas contributing to "sub" watersheds which in turn make up well defined major watershed areas was sacrificed to some extent. The delineated HRU's do not drain exclusively into any one particular adjacent land mass or defined channel. Still, as the linkages between the HRU's would have to be defined the drainage patterns were considered as much as possible.

Slope and aspect were considered important variables in the delineation of the HRU's. Both a north facing, as well as a south facing, canyon wall may be part of the same drainage sub area. They, however, will behave quite differently with respect to local water balances. Incident radiation, prevailing winds, and foliage will differ considerably from north to south facing slopes. Efforts therefore were made to separate major sections of land if they differed significantly in slope and aspect.

Elevation is linked to local temperature. Again, as with slope and aspect, efforts were made to isolate into different HRU's areas of significantly differing elevations.

In addition to the hydrologic considerations used in delineating the HRU's, potential land use was also considered. Fortunately these considerations were often in harmony with the hydrologic considerations in the final definition. The proximity to the major transportation link (Interstate Highway 17 to Flagstaff or

Phoenix) and the suitability of the land for the type of development hypothesized in this study influenced the final selection of the boundaries of the HRU's.

In the final analysis, the delineation was to a large extent a subjective judgement process. Others might approach the same area and divide it completely differently. It was decided to let the model's performance pass the ultimate judgement upon the HRU delineation. That is, if it worked well enough for then the delineation of HRUs was sufficient for the purposes of the study.

Figure 3 is a sketch of the Woods Canyon area with the delineated HRUs. The area of each HRU is shown along with the major drainage ways and their length. Table 1 shows additional information for each HRU such as: average slope, aspect, average width, average length, perimeter, length of boarder with adjacent HRUs top elevation, bottom elevation, and length of major definable drainage ways.

Figure 3: Hydrologic Response Units Within Woods Canyon (HRUs)

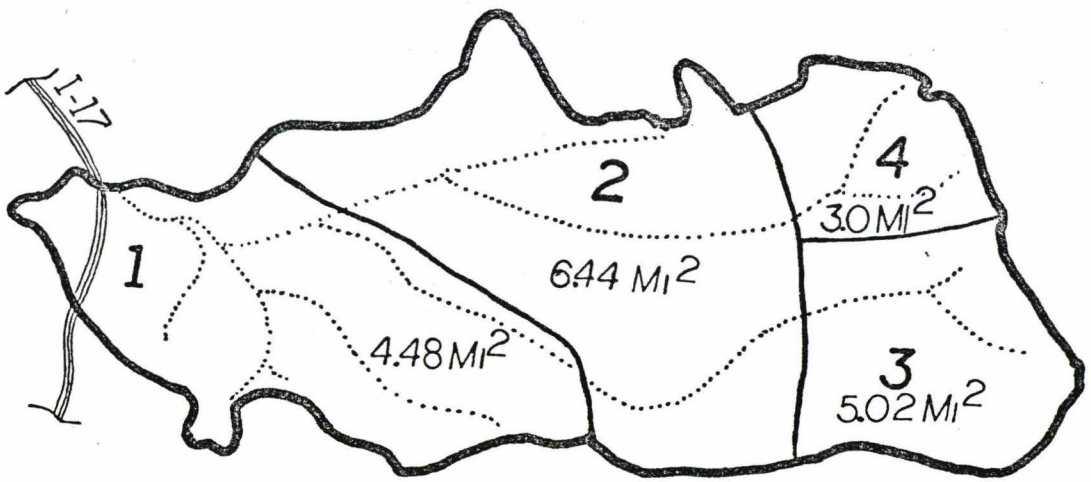


Table 1

Hydrologic Response Unit (HRU) Data

HRU	Area (Mi.2)	Ave. Slope	General Aspect	Ave. Length (Mi.)	Ave.. Width (Mi.)	Top Elev. (Ft.)	Bottom Elev. (Ft.)	Perimeter (Mi.)
1	4.48	.017	315°	4.7	1.4	6850	6370	12.2
2	6.44	.037	270°	3.0	2.3	7040	6480	11.7
3	5.02	.037	270°	2.8	1.8	7560	7000	9.5
4	3.00	.030	225°	2.5	1.2	7480	7080	8.4

Soil Types Within Woods Canyon: The types of soil and their depths is a significant parameter within a watershed. Fortunately, a detailed study of the soil types to be found in the Woods Canyon area has been completed by the Forest Service. This detailed data has permitted for each HRU the calculation of an aggregate weighted average value for the field capacity, wilting point, saturated capacity and depth of soil. Figure 4 is a reprint of the detailed soil map presented in the Woods Canyon soils study. The types of soil represented by the map symbols are identified in table 2. By summing the areas for each type of soil within each HRU a weighted average of soil parameters is readily obtained. Table 3 shows the relative percents of each soil type within each HRU. This was accomplished by measuring with a planimeter the areas for each soil type within each HRU. The aggregated weighted average of the soil types within each HRU is compared to the total percent for the entire Woods Canyon area as calculated in the Soils Report by use of a computer digitizer. The minor differences should have relatively little impact on the study results.

The values of the ground moisture and soil parameters for each type of soil are presented in Table 4 again from the Woods Canyon Soils Report. These values were combined by weighted average based on the relative percents presented above. The result of this analysis is presented in Table 5, where the aggregrate field capacity, wilting point, saturated water capacity and depth are listed for each HRUs.

Figure 4: Woods Canyon Soil Map

TABLE 2

Woods Canyon Research Watershed Soil Survey Legend

(From Soils Report - Woods Canyon Watershed Southwestern Region. U.S.D.A. Forest Service)

Map Symbol	Tentative Soil Series Name	Slope Range-%	Soil Classification	Potential Natural Vegetation	Parent Material	Depth to Par. Material
10	Friana-Seep Complex	0-15				
	Friana Loams		Pachic Argilboroll fine, montmorillonitic	Ponderosa Pine (Seral Grassland)	Old Alluv.	40"
	Seep loams		Aquic Argiboroll fine, montmorillonitic	Carex-Poa	Old Alluvium	40"
500	Rocktop cobbly loams	0-15	Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt	20-40"
501	Cruice clays	0-15	Udic Chromustert fine, Montmorillonitic Mesic	Alligator Juniper-Utah Juniper	Basalt	" "
502	Bootlegger cobbly clay loams	"	*Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine-Alligator Juniper	"	"
503	Rocktop-Brolliar-Firebox Complex	"				
	Rocktop cobbly loams		Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt	"
	Brolliar loams		Typic Argiboroll fine, montmorillonitic	Ponderosa Pine	"	"
	Firebox cobbly loams		Lithic Argiboroll clayey, montmorillonitic	Ponderosa Pine	"	20"
504	Herm-Siesta Complex	0-15				
	Herm loams		Typic Argiboroll fine, montmorillonitic	Ponderosa Pine	Basalt & Cinders	40"+
	Siesta gravelly loams		Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt & Cinders	40"+
505	Fain cobbly loams	0-15	Mollic Eutroboralf clayey-skeletal, montmorillonitic	Ponderosa Pine	Basalt	20-40"
506	Siesta loams	0-15	Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt &	40"+
510	Herm-Rocktop Complex	15-40				
	Herm cobbly loams		Typic Argiboroll fine, montmorillonitic	Ponderosa Pine	Basalt & Cinders	40"+
	Rocktop loams		Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt	20-40"
520	Siesta-Rocktop Complex	15-40				
	Siesta cobbly loams		Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt & Cinders	40"+
	Rocktop loams		Mollic Eutroboralf fine, montmorillonitic	Ponderosa Pine	Basalt	20-40"

*Proposed Subgroup of Mesic Eutroboralf

Table 3

Soil Types by Percent for
Woods Canyon Hydrologic Response Units (HRUs)

Soil Type	Percent of Total Unaggregated [1]	Percent of Total by Weighted Ave of HRUs [2]	Hydrologic Units 1	2	3	4
Friana-seep Complex	1.4	1.3	1	1	2	1
Rocktop Cobbly Loams	16.3	19.4	8	29	21	13
Cruice Clays	0.3	nill	-	-	-	-
Bootlegger Cobbly Clay Loams	5.4	4.8	10	7	-	-
Rocktop-Brolliar Loams	22.9	24.7	22	25	24	29
Herm-siesta Complex	11.9	14	16	8	20	14
Fain Cobbly Loams	3.0	4.3	0	3	4	14
Siesta Loams	8.0	5.7	4	3	7	12
Herm-rocktop Complex	10.8	8.9	13	6	7	12
Siesta-rocktop Complex	20.0	17	26	18	15	5

1) This was calculated by Forest Service for entire Woods Canyon by use of computer digitizer (U S. Forest Service, 1967).

2) This was calculated in study by planimeter for each HRU and subsequently aggregated by weighted average using HRU areas.

Table 4

Ground Water Parameters for Woods Canyon Soil Types (U.S. Forest Service, 1967)

Soil Type	Total Depth (inches)	Total Plant Avail. Water (inches)	Total Fld. Capacity (inches)	Wilting Capacity (inches)	FLDCAP[1]	WLTCAP	SATW(
1	2	3	4	(5=4-3)	(6=4/2)	(5/2)	2x(6)
Friana-seep Complex	48	7.3	17.2	9.9	.36	.21	.72
Rocktop Cobbly Loams	30	4.2	10.5	6.3	.35	.21	.70
Cruice Clays	36	5.2	12.7	7.5	.35	.21	.70
Bootlegger Cobbly Clay Loams	22	3	7.3	4.3	.33	.20	.66
Rocktop-brolliar Loams	27	3.7	8.9	5.2	.33	.19	.66
Herm-siesta Complex	63	8.5	20.3	11.8	.32	.19	.64
in Cobbly Loams	32	3.1	7.7	4.6	.24	.14	.48
Siesta Loams	65	7.6	17.2	9.6	.26	.15	.52
Herm-rocktop Complex	41	5.2	13.5	8.3	.33	.20	.66
Siesta-rocktop	43	5.6	13.6	8.0	.32	.19	.64

1) Field capacity per inch of soil as fraction of 1 inch.

2) Wilting point capacity per inch of soil as fraction of 1 inch.

3) Saturated water contents assumed to be approximately twice filed capacity.

Table 5

Averaged Soil Parameters for Woods Canyon

Hydrologic Unit (HRU)	Field Capacity (FLDCAP) % of soil depth	Wilting Point (WLTCAP) % of soil depth	Saturated Water Content (SATWC) % of soil depth	Soil Depth cm
1	32	19	64	102
2	33	19	66	91
3	32	19	64	107
4	31	18	62	102

Chapter IV

Hydrologic Background

Hydrologic Variables: Hydrologic studies devoted to watershed response generally represent the physical processes occurring at the air surface-subsurface interface by way of a simplified mathematical model, or water budget. This theoretical system is based upon an accounting procedure which through a summation of hydrologic debits and credits results in an estimation of the net change in system storage per unit time. The model takes the form of the differential equation:

$$I - 0 = \frac{dS}{dt}$$

Where I and 0 are the hydrologic inputs and outputs respectively and the differential $\frac{dS}{dt}$ refers to the change in storage. The outwardly manifest elements in this model are precipitation inputs, either snow, rain, or mixture, and runoff which may appear as surface (overland) or subsurface flow. These variables are mitigated by a number of hydrologic abstractions which derive from the complex mediation of the ecosystem with water transport. Changes in land use affect not only individual parameters, but their dynamic interaction as well. In the following pages, the potential impact of development upon these hydrologic variables is discussed.

Interception: A portion of the precipitation which falls within a watershed is intercepted by vegetation as well as other protrusions from the ground surface. Additionally, a variable proportion, termed throughfall, will clear the forest canopy uninhibited by obstructions and proceed directly to the forest floor. Intercepted precipitation will at some point in time, depending on its form, either evaporate from vegetative surfaces or exit downward through the canopy as drip or stemflow and eventually reach the ground surface.

Measurement of intercepted precipitation is usually accomplished by subtracting the value of in-forest precipitation catch from that obtained from a

nearby open field gage. This estimate is necessarily a rough one due to the neglect of stemflow. However, this component is generally considered negligible for coniferous stands. Its significance, however, has been noted for some deciduous species (Eagleson, 1970).

The timing involved in the release of foliar-intercepted rainwater is dependent upon the stage of storage capacity attained during the storm. This storage capacity is a function of the nature of the leaf surface, the angle at which leaves hang, and their total area (Miller, 1977). Outflow via branch and stemflow approaches an equilibrium with the incoming precipitation only after storage capacity has been fulfilled. In forested regions, net precipitation, defined as throughfall plus stemflow may vary from 0 to 95 percent of gross precipitation, this differential being a function of storm and species characteristics (Hewlett and Nutter, 1969). Evaporation potentials notwithstanding the duration of canopy storage is less a concern of the present study than the volume of rainwater which ultimately arrives at the forest floor and contributes further to the mass water balance.

The mechanics of snowfall interception are much more complex than that pertaining to rain. Variables such as density and structure of snowflakes, wind speed, and air temperature affect the impaction process which creates an immense storage potential in the forest canopy. However, these same factors may also force a reversal of the process. Solar radiation and strong winds, aided by the turbulence produced by rough forest stands, are capable of removing accumulated snow from impacted branches. Reception of solar radiation pulses is also sometimes sufficient to melt the base layer of plastered snow resulting in the sliding of a snow mass from its anchoring branch (Miller, 1966).

Construction on second home sites as well as appurtenant small scale commercial development will certainly reduce interception of precipitation in the Woods Canyon area. The difference between developed and undeveloped inter-

ception could be expected to be more pronounced during rainstorms than snowfall periods due to storage, albeit temporary, of snow by man-made structures. However, because of the influence of heat conduction from underlying materials, a factor which is essentially negligible in soils of forest stands, the melting of these isolated accumulations would proceed quickly.

Interception will be adversely affected wherever vegetation is removed in the development process. This results from a loss of storage volume inherent in both tree and lower vegetal stratums. This results from the total leaf areas of both which amounts to between three and six times the ground surface area.

The influence of a reduction in intercepting area on the aggregate streamflows of the Woods Canyon region would appear questionable. Empirical studies, such as that carried out by Gary (1974) for a lodgepole pine forest in Wyoming, seem to imply that forest openings don't affect the total quantity of snow delivered, but rather effect a translocation of intercepted snow through the action of local aerodynamic forces. Evaporation opportunities for snow cover have been shown to be minor for interior continental mountain ranges (Hoover and Leaf, 1967). Therefore, the majority of fallen snow is likely destined for conversion to melt water, contributing either to soil moisture and percolation or surface and subsurface runoff. If any effect is envisioned, it is the timing of meltwater release which will be accelerated due to the loss of a portion of the stabilizing forest enrirons. This may provoke a redistribution of monthly streamflow volumes and lead to a reduction in the longevity of seasonal streamflow in ephemeral channels.

Detention and Depression Storage: Once the infiltration capacity is reached over a certain area, a film of water will build up on permeable and imperable surfaces. In addition, natural depressions will store water which is then evenually infiltrated or evaporated. These abstractions, defined as detention storage and depression storage, affect the timing of runoff to a greater degree than they affect volume of stormflow. In combination they could be expected to change only slightly in response to second home construction.

Evaporation and Transpiration: Evaporation from wet soil and vegetal surfaces and transpiration, which acts through the vaporization of water from living cells of plant tissues, may be approached as quantitatively different entities. Since both processes physically involve the vaporization of liquid water they are often collectively referred to as evapotranspiration.

All evaporative processes require the availability of energy and, of course, water. Inputs of energy which drive the evaporative mechanism are short and long wave solar radiation, sensible heat (heat used to warm the environment without a change of state), and wind, a potentially important factor in forest stands.

As mentioned above, evaporation from snow surfaces is a negligible abstraction from the hydrologic process at higher altitudes. Seldom are the energy requirements of evaporation met by winter and spring air masses. Warm, dry air is needed for sublimation in the snow environment. Correspondingly larger amounts of radiant energy are required to evaporate snow than to melt it. More often, the intrusion of moisture-laden warm air masses will promote condensation at the snow-air interface mitigating against direct evaporation.

Evaporation from wet surfaces, be it soil, litter, or arboreal is relatively efficient in its utilization of available energy. Rain moisture also maintains a greater absorptivity of solar radiation than snow which has a high albedo. The aggregate evaporation from intercepted rainfall is dependent on the frequency of precipitation events. The more times interception storage is filled, the greater the evaporative opportunities.

Transpiration will fluctuate according to the supply of radiant energy, turbulent mixing by wind currents, nature of leaf surfaces, and the state of internal plant water relations. Increases in streamflow volume have been attributed primarily to transpiration reduction in a wealth of studies including that by Galbraith (1975) for forested regions of western Montana.

Removal of tree stands in the Woods Canyon watershed would logically be expected to reduce evapotranspiration in the area. Even with the protection or regeneration of low lying vegetation in the harvested areas, the removal of the deep forest canopy would decrease the possibilities for evapotranspiration potential of forest canopy from that of the low vegetation. Galbraith concludes that the forest more often exhibits a higher rate of evapotranspiration. Rauner (1960, 63, 65) has also shown that warm air advection, certainly expectant over north central Arizona, enhances this increased rate.

Infiltration: Before the runoff process is initiated, a portion of the water occurring at the ground surface is extracted by the soil system. This phase in the redistribution of water influx, referred to as infiltration, is dependent upon a variety of soil and ground cover factors (Hewlett and Nutter, 1969):

1. Antecedent water content of the soil.
2. Biological activity and organic matter.
3. Soil texture and structure (porosity).
4. Depth and type of mulches, forest floor, or vegetal cover.
5. Surface soil absorptive capacity.
6. Soil frost and ice (concrete or granular).
7. The quality of infiltrating water (silt, chemicals, debris).
8. Entrapped air in underlying soil.

The vertical movement of water through the soil is governed principally by capillary forces which act to hold water by tension. These forces are realized in what is termed the "capillary potential", Ψ. Therefore, the mathematical description for downward flow: flow=K $\frac{2\Psi}{2\chi}$ in which X is vertical distance and K is a proportionately coefficient called "capillary conductivity" which itself is a function of soil moisture, and soil structure and porosity.

Infiltration rates are probably the most uncertain of all hydrologic parameters. Not only do these rates vary seasonally, a result of fluctuations in

vegetal activity, but differences are even apparent from storm to storm. Higher rainfall intensities often result in sealing of entry pores. This impact-produced effect causes an in-washing of fine soil particles which impedes the infiltration process. However, in forested areas where sufficient ground litter exists to eliminate this disruption, it is a decrease in the capillary potential which accounts for the concurrent decrease in the rate of infiltration (Bodman and Colman, 1944).

The rates of infiltration capacity exhibited by forest soils are usually greater than prevailing rainfall intensities. Thus, surface runoff is seldom experienced over an undisturbed forested watershed. There are exceptions, though, and the shallow, clayey soils prevalent in Woods Canyon evidently provide relatively low infiltration capacities (Rogers, personal communication). The action of continuous degredation of the forest floor by grazing, logging, road building, and human usage (hunters, recreationists, etc.) should also impair infiltration rates in the affected areas (Hewlett and Nutter, 1969). This intensified usage may expectedly play a role in the hydrologic response of the Woods Canyon basin to establishment of a second home, recreation-oriented community. The extent of this alteration will, as with previous abstractions, be a function of the nature and degree of development.

Percolation: The progressive movement of water through the soil profile into the ground water system is an essential component of the water budget in humid regions. But in the semi-arid environment of Arizona, most channel systems are ephemeral in nature. Percolated water reaching deep-seated groundwater systems is thus neglected in the present study.

Runoff: The hydrologic response of forested watersheds has generated much debate over the years. Disagreements have centered around the concept of infiltration and its relative prominence in the runoff scheme. Recently, however, the position advanced by a number of forest hydrologists (e.g. Hewlett and Troendle, 1975) stressing the secondary importance of infiltration

has gained credence especially amongst those concerned with process-oriented hydrology.

Contrary to previously held theories describing forest runoff in terms of overland flow (Horton 1945, et. al.), the variable source area concept (Southeastern Forest Experiment Station, 1961) discards the notion that infiltration and resultant overland flow are the primary motivations for stormflow in forested basins. Instead priority is given to the processes of channel precipitation (precipitation directly entering the stream channel) and an expanding and contracting channel network which responds to incremental changes in upslope subsurface storage and concurrent downslope movement of soil water. This down slope movement is thought to occur along a plane or sets of planes nearly parallel to the surface, under the influence of a hydraulic gradient which in turn depends on local moisture contents, soil conductivites, and basin slope.

Because of the integral position of subsurface runoff in the movement of storm generated flow or snowmelt into channel systems, prescribed conductivities for different soil groupings should have a major effect on any reliable runoff prediction mechanism. Construction along stream channels may affect the flow pathway or, depending on slope alteration, influence the positioning of expanded channel boundaries during storm events. Nonetheless, it seems questionable whether development in the Woods Canyon region would affect soil conductivities and the variable source area flows it induces. With regard to the overland flow component, removal of forest stands and the compaction of soil strata due to the continual traffic, human and otherwise, over cleared areas, should increase the already high surface runoff potential in the basin.

Chapter V

Hydrologic Simulation

Vast quantities of work have gone into hydrologic simulation of watersheds. The products of these efforts have helped to answer the questions dealing with the response of a watershed (generally undisturbed natural watershed) to particular rainfall distributions. Of significant importance among the models available are the Continuous Streamflow Simulation Models which go beyond the Rainfall Runoff Event Simulation models by keeping running records of a watershed's hydrologic state both between and during rainfall periods. Once calibrated they can help answer some of the "what if" questions posed by forest managers. Many of the available hydrologic models are listed below in table 6 (Viessman, 1977).

Table 6

Major Continuous Streamflow Simulation Models

Code Name	Model Name	Agency	%Input by Judgement	Date of Orig.Dev.
API	Antecedent Precipitation Index Model	Private	1	1969
USDAHL	1970,1973,1974 Revised Watershed Hydro.	ARS	1	1970
SWM-IV	Stanford Watershed Model IV	Standford U.	10	1959
KWM	Kentucky Watershed Model	U. Kentucky	10	1969
OPSET	Self-optimizing Hydro. Simulation Mdl.	" "	5	1970
HSP	Hydrocomp Simulation Program	Private	10	1967
TWM	Texas Watershed Model	Texas Tech. U.	10	1970
NWSRFS	Natl. Weather Ser. Runoff Forest Sys.		10	1972
SSARR	Streamflow Synthesis & Reservoir Reg.	Corps	3	1958
OSUSWM	Ohio State U. Version of SWM-IV		10	1972

(From "Introduction to Hydrology", V. Viessman, Knapp, Lewis, Harbaugh, by Harper & Row, 1977 p.409)

The USDAHL continuous simulation model has been increasing in popularity as interest has grown in the effects of various proposed changes in the watershed (including changes in vegetation, pavements and farming practices) upon infiltration and overland flow. This fairly comprehensive model requires significant quantity of data and the initial estimation of many of the watershed's hydrologic parameters. The Stanford watershed model (also a continuous stream flow simulation model) and its many varients is another popular tool for studying the hydrologic system governing water movement in or on a watershed. It has been successfully used to synthesize a continuous hydrograph of hourly or daily streamflow at a watershed outlet given a completly defined watershed.

ECOWAT: The watershed simulation model ECOWAT developed by J. Rogers (1975) is the vehicle used in this study to evaluate the effects of second home development on the hydrologic response of Woods Canyon. The model was assembled to represent ecosystem dynamics indigenous to the coniferous forest biome. A brief summary of the interaction between altered hydrologic parameters and model components follows. Detailed explanation of ECOWAT formation and procedure may be found in "Contribution to Woodlands Snythesis, Ecosystem Dynamics Section, Water Relations and Hydrologic Cycles", (Waring, Rogers, and Swank, 1975).

Canopy Water Balance Component: Water balance in the forest canopy as considered in the model has adequate parametric capacity with which to simulate changes in evaporation. Since the canopy water holding capacity is described in terms of leaf, branch, and stem area, and vegetative type, storage capacities and their depletion and recharge should be satisfactory expressed. In addition, evaporation of excess snow in canopy storage is neglected in favor of its redistribution to the ground surface. This is in keeping with the stance taken by the present authors who reject the primacy of the concept of excessive evaporation from intercepted snow as a determinant in the water yield process.

Snowpack Component: ECOWAT's treatment of snowpack energy and water balance realizes the thermodynamic energetics involved in the snowmelt reaction. It required inputs are compatible with available information on Woods Canyon and should therefore present no problems in evaluating changes in snowmelt characteristics resultant from redistribution of incoming precipitation to denuded areas.

Litter Water Balance Component: The litter layer found in forest regions is an important source of moisture storage which also increases the evaporative potential of the water influx. Its displacement will most probably influence soil disruption and therefore infiltration capacities and subsequent runoff. The litter water balance component successively evaporates moisture from storage, transmits it through the litter, and passes moisture through litter openings. This litter component is significant in that it may affect the surface water balance even in partially cleared areas depending upon the degree of degredation practiced and the nature of construction at second home sites.

Surface Water Balance Component: Essentially, this segment handles detention storage, infiltration, and overland flow. Changes in infiltration capacities due to antecedent conditions, and construction and use activities should be sufficiently accounted for by this component. Short term fluctuations due to variations in storm intensity will have to be assimilated into an average value typical of the local meteorology. However, exaggerated accuracy in this regard is probably unwarrented given that of other model parameters.

Soil Water Balance Component: This component covering percolation, lateral flow, and non-capillary flow within the soil system will model critical soil conductivity and the lateral flow process which contributes to aggregate streamflows in the channel system. Aside from soil water utilized in the transpiration process (plant-water component), developmental impact upon the soil water balance is expected to be negligible.

Plant Water Relations Component: The simulaton by this component is crucial to the successful assessment of changes in water yield. Transpiration, as mentioned earlier, is expected to withdraw the greatest percentage of water from the watershed system. The more precise the model component functions, the more probable reliable conclusions can be made.

Detailed description of the plant water relations encompasses consideration of water uptake, transpiration, internal storage, moisture stress, leaf resistance, and surface resistance. Ponderosa pine is predominant at the experimental site; however, there is also a number of deciduous trees (Gambel oak). Deciduous species must rely totally upon uptake through the soil-root system while coniferous trees are capable of drawing from an internal storage reservoir. This component is a potentially sensitive indicator of the internal water relations which govern transpiration losses. The authors have pointed out, though, that data inputs for these factors are rarely available for vegetation on forested basins.

ECOWAT Simulation History: Lending a precedent to the present study, ECOWAT has previously tested in simulation in another experimental watersheds which combine to form the Beaver Creek Watershed, of which Woods Canyon is a subunit. Watershed 17 was subjected to a heavy thinning treatment in 1969. Water yield results showed close agreement (5% deviation) with actual streamflow increases for the year 1973.

Simulated Development: In order to appraise the long term impacts of development upon streamflow, six levels of development were simulated for the Woods Canyon watershed. These ranged from a no development situation to a complete development situation with a fairly high density. The high density situation was provided to approach a quarter acre subdivision with paved streets.

Development was simulated in six phases which progressed from the lowest elevation HRU up to the highest. Fortunately, for the Woods Canyon area this

also allows the development to proceed from areas in close proximity to the major transportation link to areas more remote, steeper, and less suited for development. Table 7 illustrates the progression of development simulated.

Table 7
Development Level

Simulation Number	HRU-1	HRU-2	HRU-3	HRU-4
1	0	0	0	0
2	½	0	0	0
3	½	½	½	0
4	1	½	½	½
5	1	1	½	½
6	1	1	1	½

0-Zero Development
½-Moderate Development 1-3 acre subdivision approximately 50% built
1-Full Development, ¼-½ acre subdivision approx. 75% built.

Many hydrologic variables are effected by this type of development. Not all the changes in affected hydrologic variables could be explicitly modeled. Watershed parameters which appeared to be the most sensitive to development and which seemed to have the most effect upon a watersheds productivity were chosen.

The variables which were deemed most sensitive to the simulated development were: a) The density of the canopy cover (normal, summer and winter); b) Water holding capacity of the litter; c) The density of foliage on the forest floor, d) The fraction of global radiation attenuated by the vegetative cover; e) The saturated conductivity of the soil ; f) The saturated water content; and g) average soil depth. Development results in the partial clearing of the land. Regardless of the developers intent to "save trees" the earth moving, grading, and paving operations inevitably remove significant numbers of trees. This seems to be proportional to the density of development since more roads are needed to service a more finely divided area. It has been estimated for the purposes of this study that for the moderate development described above

there would be a 25% decrease in the forest canopy cover. Full development would reduce the canopy cover even in a "good" development by 50% or more.

The litter on the forest floor, on the average, can suffer a significant decrease in its ability to hold water with increasing density of development. Significant areas are cleared of all litter by the process of developing the land and building the structures. Within this study it was estimated that a 25% decrease in the total water holding capacity of the litter would result from moderate development and a 50% decrease would result from full development. It is noted that there could be significant recovery of litter in some areas of a developed HRU but this could be offset by an increase in intense land use in other areas over the same time.

The density of foilage on the forest floor suffers the same as does the trees and litter. The same factors of 25% and 50% decrease with moderate and full development respectively were used as estimates of developmental impacts.

As the ground cover and canopy cover are decreased there is a corresponding increase in the percentage of global radiation which reaches the ground. It is estimated that in the undeveloped condition, only 20% of the total radiation reaches the ground. With development, the percentage increases to approximately 40% partial development and to 60% with full development.

The hydrologic simulation model used in this study does not include an explicit input parameter describing infiltration. Infiltration is seen to be the result of the complex interaction of water, ground litter and soil qualities. To simulate changes to what is commonly referred to in urban hydrologic studies as urbanization (the ratio of impervious surfaces to pervious surfaces) the parameters of soil conductivity, saturated water content, and soil depth were used. The saturated conductivity of the undisturbed soil which is the ultimate limitation upon infiltration was estimated at about 0.7 cm./minute (1000 cm./day). It was further assumed that the average conductivity of each HRU would be affected by the development in that HRU. In the full development situation

one quarter to one third of the land surface could be sealed off from infiltration. This could result in a net decrease of the average conductivity in that HRU of roughly the same amount (25-33%). Consequently, with full development the average saturated conductivity for the affected HRU was assumed to be 0.5 cm./minute (approx. 700 cm./day). For moderate development 0.6 cm./minute was assumed (approx. 860 cm./day) as an average value for the affected HRU.

Using much the same logic as was used above for the saturated conductivity, parameters describing saturated water content and soil depth were also modified from the original values. It was realized that development would cut off large areas from infiltration altogether. It was therefore decided that the total moisture holding content of the soil would be reduced. The total moisture present in a HRU is a function of soil moisture and soil depth. To simulate the desired changes, the average soil depth and saturated water content for developing HRU's were decreased by approximately 15 and 30 percent respectively for partial development and full development. Table 8 summarizes the values chosen for the variables used to reflect changes in the land use of the HRU's.

TABLE 8

Values of Hydrologic Variables
for Various Levels of Development

Variable Name	Hydrologic Variables	Development Level		
		Zero Development 0	Moderate 1/2	Full 1
COVMAX	Canopy Cover Density (%)	1.00	.75	.50
ELTCAP	Water Holding Capacity of Soil liter (cm)	1.00	.75	.50
ELTCOV	Foliage Density on Forest Floor (%)	1.00	.75	.50
ATNMAX	Fraction of Radiation Stopped by Canopy (%)	.80	.60	.40
SATK	Saturated Conductivity of Soil (cm/day)	1000	860	700
SATWC	Saturated Water Content cm^3/cm^3	.52	.45	.36
DEPTH	Soil Depth % of original value	100	80	60

Chapter VII

Overview

The major goal of this endeavor was to detect if possible, any long range changes in a watershed's water yield which were related to development of an urban nature. The changes in water quantity that would be most significant to a watershed planner would be the total volume of streamflow, the peak season flow and the timing of peak flows. These parameters have significance beyond that of the watersheds immediate response to particular events and how that might change with different levels of development. The trends found in the grosser aspects of volume, peak, and time to peak might be more readily transferred to different situations. They are also of more fundamental significance for the long range water related planning decisions dealing with water supply.

The method chosen to isolate the sought after effects was based upon a hydrologic simulation. Such a simulation is in essence a complex water accounting scheme. It bears resemblance to nature only to the extent that its inter-linking relationships are sufficient to account for the deterministic aspects of nature. The argument would be made that any development related changes in the streamflow as predicted by the model could be viewed simply as the models sensitivity to its own modeled parameters and not necessarily the true response of the actual watershed to the postulated changes. This, however could be said in any modeling situation where the model is used in a "what if" mode. This doesn't weaken the force of the argument but places, rather, greater importance upon the use of only the grosser aspects of the prediciton. No attempt is made to look at daily flows in the "what if" situations but, rather, seasonal totals and yearly trends are considered. Thus, if the model performs reasonably well in the calibration tests its performance in the grosser aspects of the "what if" situation is more credible.

Calibration and Simulation

As runoff data was also available for the four year period for which the other necessary hydrologic data was available (1967-1970 inclusive) a calibration phase of the study was conducted. Model base line parameters were adjusted to attempt to bring predicted flows in line with actual measurements, without comparing the field measurements of these parameters. This was accomplished by making the necessary adjustments within the error band of the original parameter estimates. Despite this calibration attempt the model overestimated by almost 100% the total flow in 1967. This is partially explained by the extreme hydrologic conditions found in that year. Table 9, however, illustrates that the average annual flows in years 1968, 1969 and 1978 were simulated more accurately with the total flow error averaging only +6%.

Table 9
Calibration Results-Average Annual Flow (cm.)

Year	1967	1968	1969	1970
Predicted Total	19.5	11.1	21.6	7.5
Measured Total	10.0	13.0	20.3	7.7
% Error	+95.0	-14.6	+6.4	-2.6

These results again illustrate the importance of the cautionary remarks mentioned earlier. Under more normal situations the model will be useful in predicting the changes in the grosser aspects of the annual streamflow hydrograph.

Table 10 illustrates the peak flow month of the predicted annual hydrograph and the actual hydrograph. The one and two month mismatch experienced in years 1968 and 1969 is viewed as a result of small differences in the individual totals for the two or three most significant months in each year. These two or three months had total flows which were close and only a slight error in any of these months would cause the shift of peak flow as seen.

Table 10

Calibration Results Peak Month

Year	1967	1968	1969	1970
Predicted Max. Mo.*	12	12	2	-9
Actual Max. Mo.*	12	2	1	-9

*Numbers indicate months with January being 1 and so on.

Table 11 shows the average annual flow for each year simulated and for all six levels of hypotheized development. Also, shown are the peak months for each year and level of development. It can be seen that there is a steady increase in average annual flow with development. Model year 1967 shows a 40% increase in flow with the full development situation while model year 1970 shows almost as much with just the first level of development and an almost 400% rise in flow with full development. Years 1968 and 1969 also show marked increases with full development 100% and 50% respectively. The rise in flow with development appears steady with the level of development. There appears to be no significance to a regression analysis, however, since the levels of development were defined arbitrarily as simple fractions of existing conditions in a progression of 1 through 6. This was done to satisfy the need for minimizing computer runs. The statement that runoff from a previously forested watershed seems to be positively affected over the long run by development of an urban character seems to be the only significant result of the study.

Table 11

Average Annual Flow and Peak Month vs. Development Level

(Flow is in cm. indicating equivalent depth over watershed)

Development Level	Model Year 67	68	69	70	
1	19.5	11.1	21.6	7.46	
2	21.5	14.3	24.3	11.6	
3	22.6	16.8	26.8	15.9	Average Annual Flow (cm.)
4	24.7	19.9	29.7	21.1	
5	25.9	21.8	31.7	24.4	
6	26.9	23.4	33.3	27.2	
A	10	13.0	20.3	7.7	
1	12	12	2	9	
2	12	12	2	9	
3	12	12	2	9	
4	12	1	2	9	Peak Month
5	12	1	2	9	
6	12	1	2	9	
A	12	2	1	9	

The phasing of the flows and their peaks appears to be vertually unaffected in all cases by development. Although development seems to delay the peak flow slightly in model year 1968; model year 1969 shows the opposite effect. If the graphs of average monthly flows are viewed (Appendix A) these differences in peak flow month seem to lose significance, reflecting only a moderate to small shift between flows in two or three adjacent months all having significant flows.

Conclusions and Recommendations

The long range effects of development upon streamflow seems to be more quantatitive than temporal. That is, although significant changes in total monthly and annual flows (measured by average monthly or average annual flows) were encountered as development increased, the large scale phasing of those flows seemed to be affected little by development. This seems to in concert with the view of urbanization sealing off large quantities of earth and resulting in enhanced streamflow. It is to be remembered, of course, that even in highly urban settings this increased streamflow is often at the expense of ground waters which could sustain the flow in the stream through drier periods. So net annual increases of flow are not obviously expected when due consideration is given all the countervailing hydrologic factors affecting a forested watershed.

As a planning input, the results of this study seem to indicate that development will have no long range adverse quantitative effects upon water systems depending upon the developing area as a contributing watershed. (Qualitative aspects may however be effected.) Further, water harvesting effects seem to predominate, actually increasing the net productivity of the area. The degree of the effect seems to vary significantly depending upon not only the degree of development but the quantity and temporal distribution of precipitation as well. (Short range changes may, however, be adverse as the watersheds response to particular events may be changed. This may result in greater flooding threats during extreme and short lived meteorlogical events.) Planned development could have less of an effect on watershed productivity if attention is paid to ground cover and natural forest floor litter as well as simply saving trees and providing open space.

The scope of this work did not permit sensitivity analysis. The watershed development simulated affected many parameters together in a progressive manner. Consequently, it is impossible, from, this study to identify which parameter was most important. Canopy cover, ground cover, litter, soil depth

and quality etc., may all respond to development and in turn may affect the hydrology of the area independently of each other. Further studies in these areas (separately) could focus the results of this study further into developmental criteria for maintaining or modifying in a planned and coordinated way the productivity of watersheds.

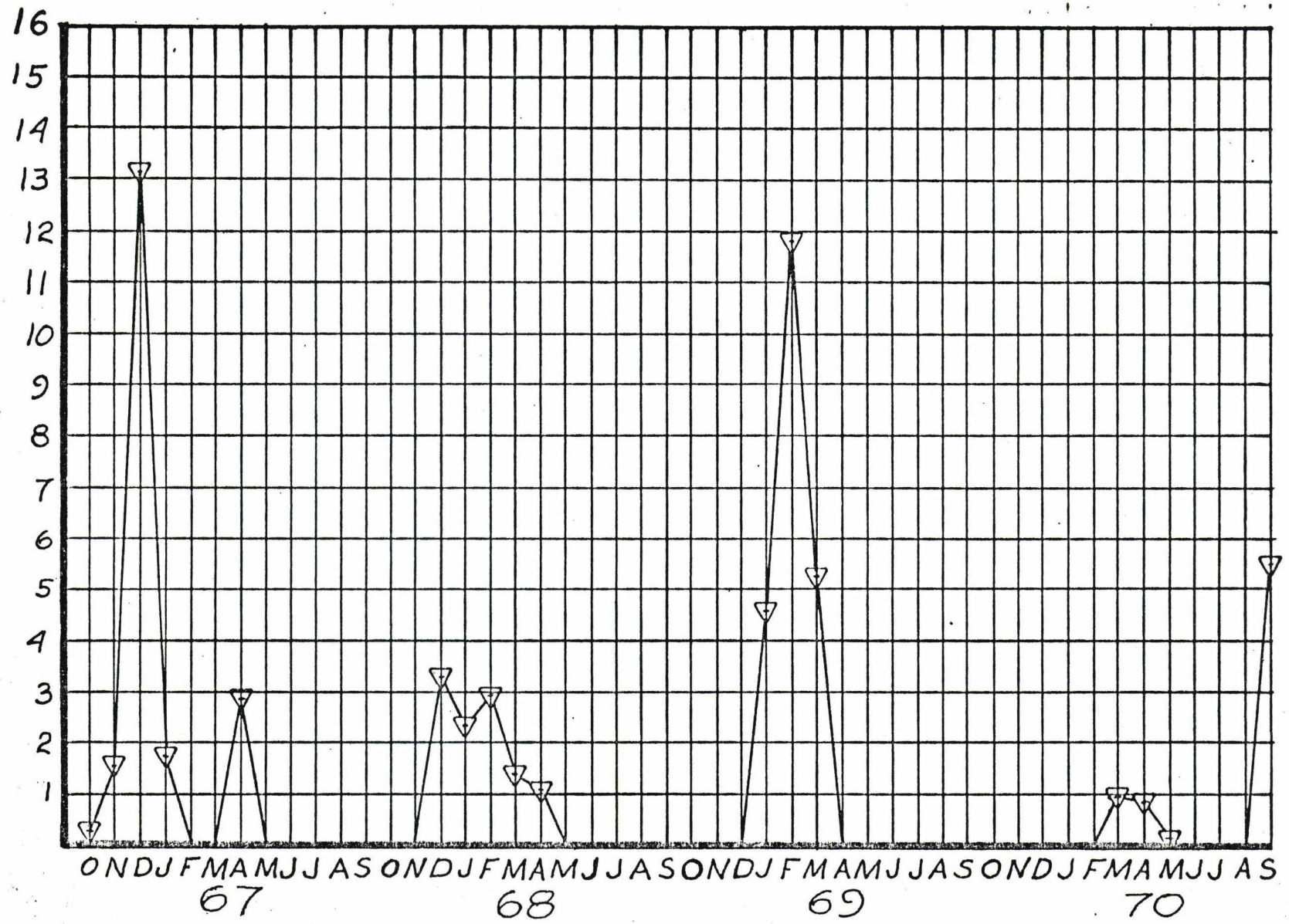
Model studies ultimately rely upon calibration and real world comparison for their validation. These results could, therefore, point to the types of responses expected in a developing watershed and thereby facilitate the establishment of accepted criteria. Long range longitudinal studies on particular developing watersheds (which was originally anticipated in this study) is still of great value. It is hoped that this study could aid in identifying the effects expected.

APPENDIX A
Parameters Used in Computer Runs (1 Through 6)

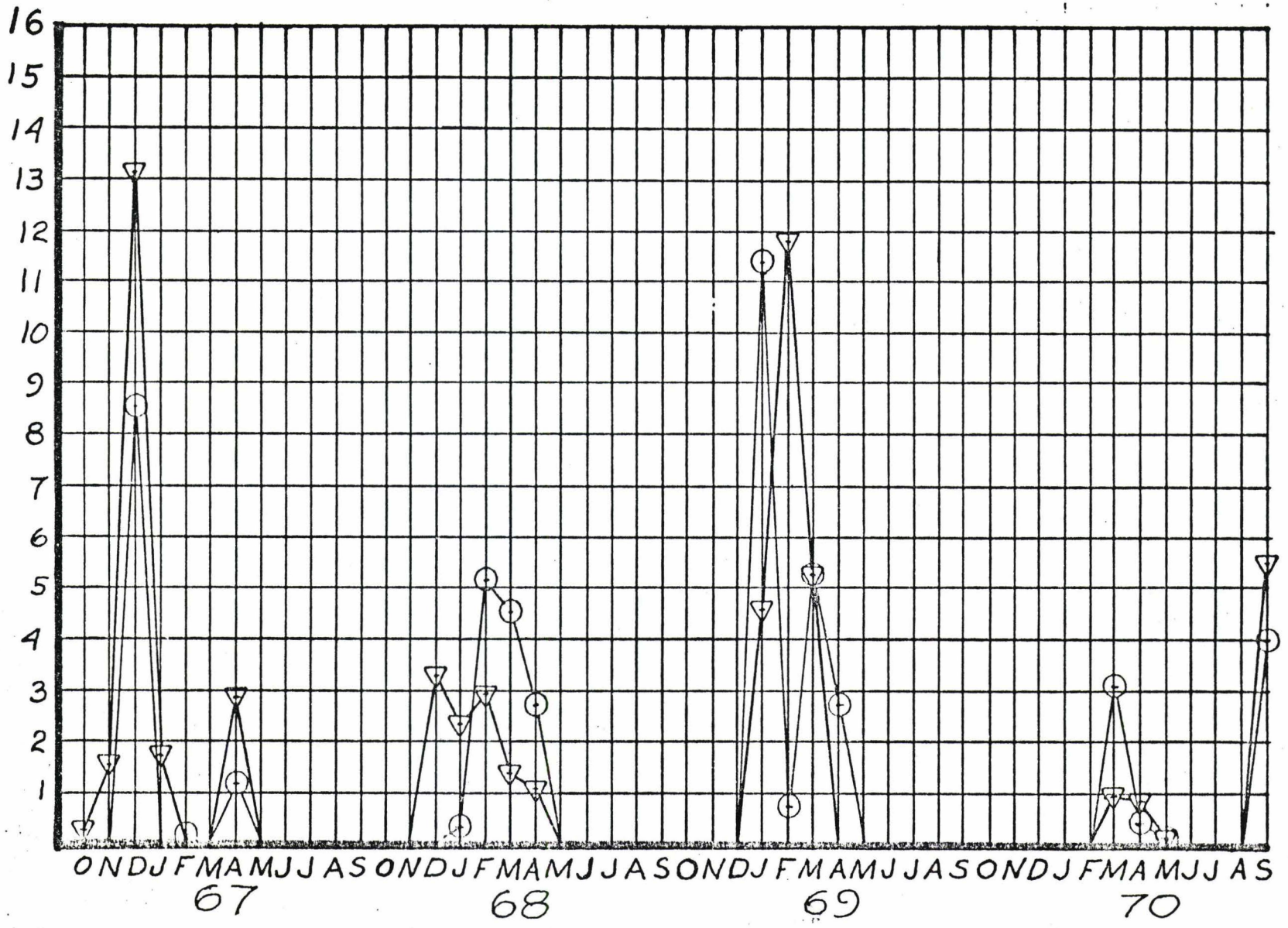
		HRU#1	HRU#2	HRU#3	HRU#4
COVMAX*	1	1.0	1.0	1.0	1.0
	2	.75	1.0	1.0	1.0
	3	.75	.75	1.0	1.0
	4	.5	.75	.75	.75
	5	.5	.5	.75	.75
	6	.5	.5	.5	.75
ELTCAP (cm)	1	1.0	1.0	1.0	1.0
	2	.75	1.0	1.0	1.0
	3	.75	.75	1.0	1.0
	4	.5	.75	.75	.75
	5	.5	.5	.75	.75
	6	.5	.5	.5	.75
ELTCOV*	1	1.0	1.0	1.0	1.0
	2	.75	1.0	1.0	1.0
	3	.75	.75	1.0	1.0
	4	.5	.75	.75	.75
	5	.5	.5	.75	.75
	6	.5	.5	.5	.75
ANTMAX*	1	.8	.8	.8	.8
	2	.6	.8	.8	.8
	3	.6	.6	.6	.8
	4	.4	.6	.6	.6
	5	.4	.4	.6	.6
	6	.4	.4	.4	.6
SATK(cm/day)	1	1000.	1000.	1000.	1000.
	2	860.	1000.	1000.	1000.
	3	860.	860.	860.	860.
	4	700.	860.	860.	860.
	5	700.	700.	860.	860.
	6	700.	700.	700.	860.
SATWC(cm /cm	1	.52	.52	.52	.52
	2	.45	.52	.52	.52
	3	.45	.45	.45	.52
	4	.36	.45	.45	.45
	5	.36	.36	.45	.45
	6	.36	.36	.36	.45
DEPTH(cm)	1	102.0	91.0	107.0	102.0
	2	82.0	91.0	107.0	102.0
	3	82.0	73.0	86.0	102.0
	4	61.0	73.0	86.0	82.0
	5	61.0	55.0	86.0	82.0
	6	61.0	55.0	64.0	82.0
GENERAL DEVELOPMENT LEVEL	1	0	0	0	0
	2	½	0	0	0
	3	½	½	½	0
	4	1	½	½	½
	5	1	1	½	½
	6	1	1	1	½

*Dimensionless Description of Density (0.0 1.0)

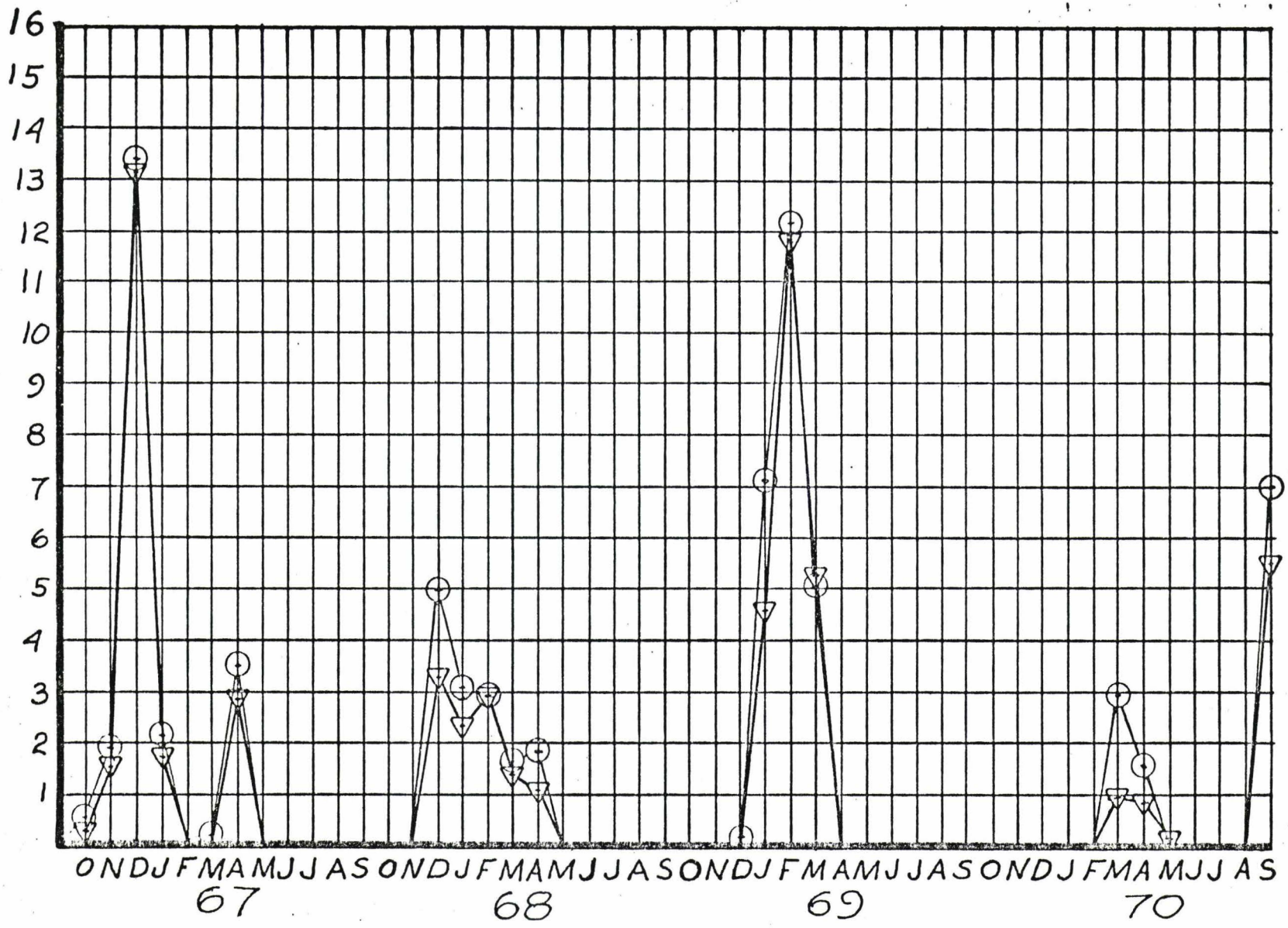
APPENDIX B
Monthly Flows
O Actual Measured Flows



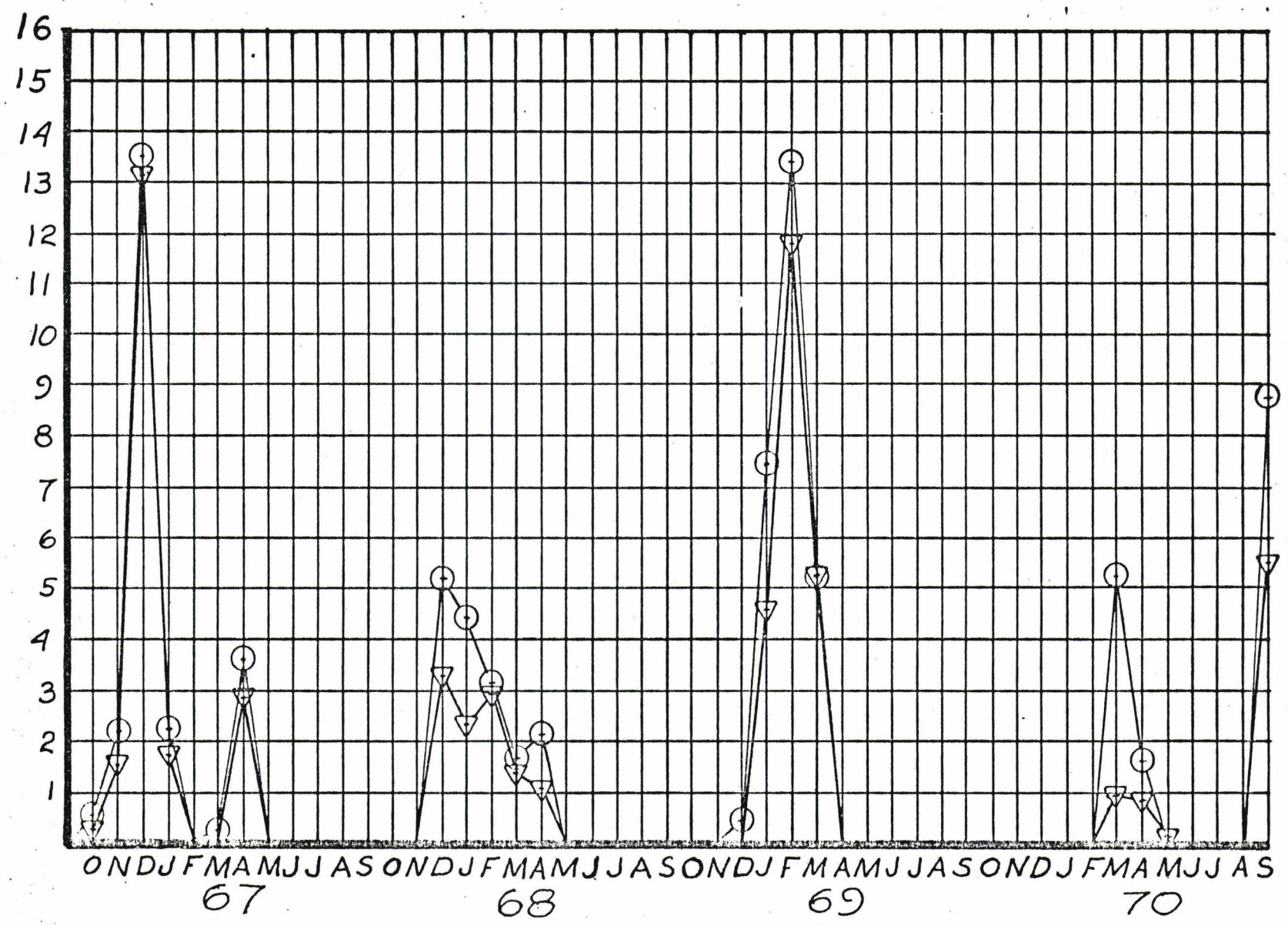
1 Actual Flows (▽) vs. velopment Level (0) (Zero Development)



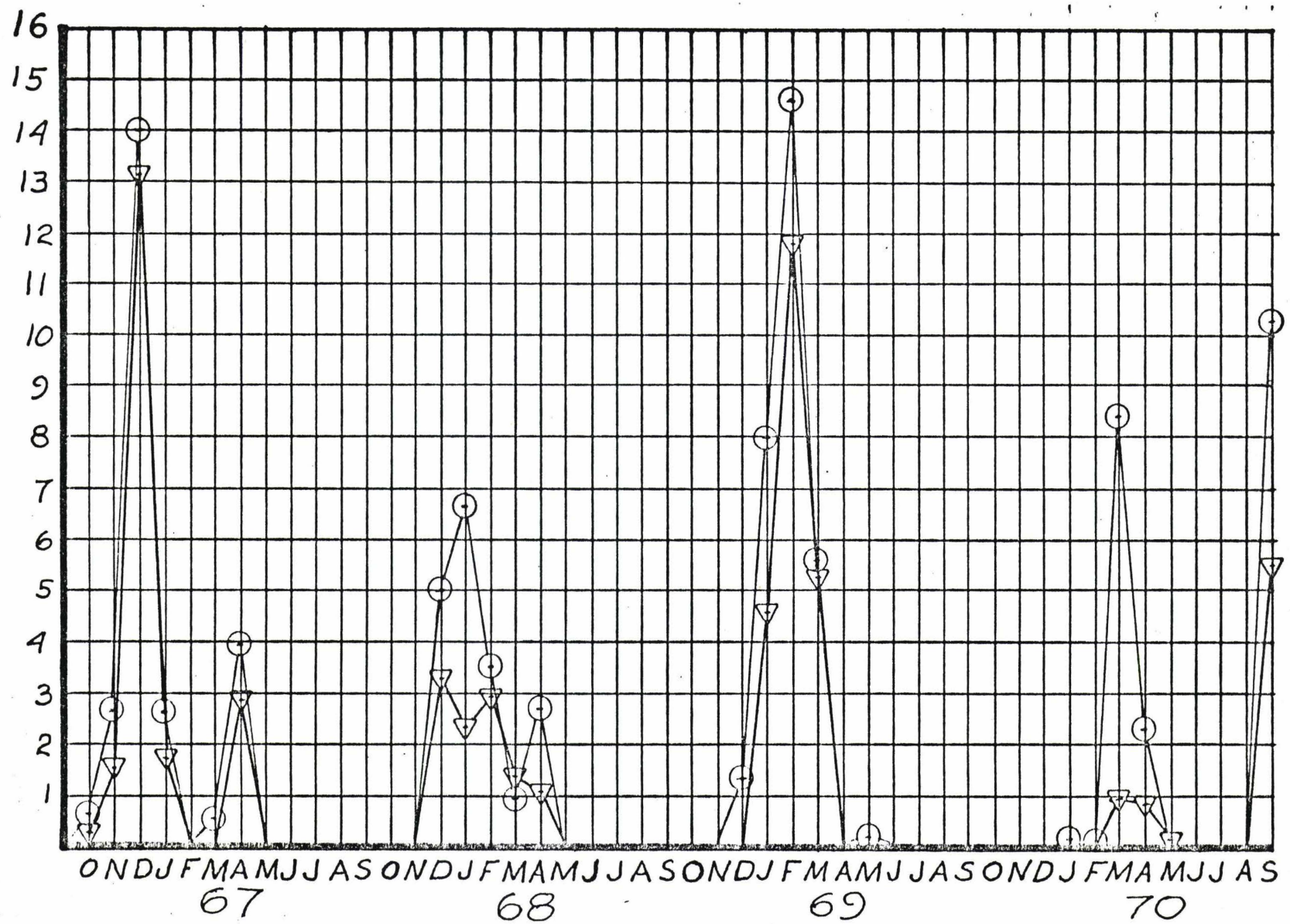
2 Actual Flows (vs. Development Level 2 (O)



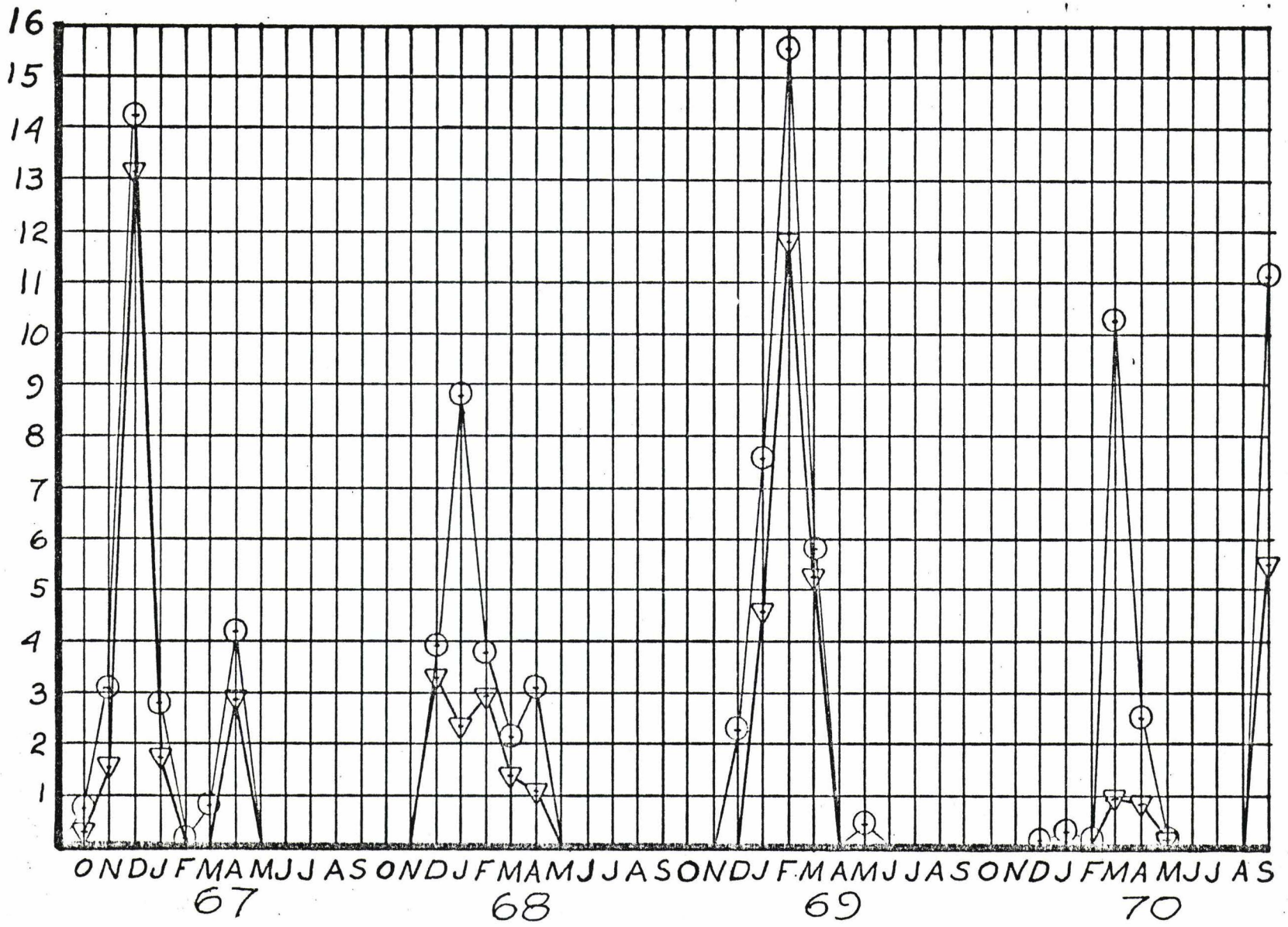
3 Actual Flows (vs. Development Level 3 (O)



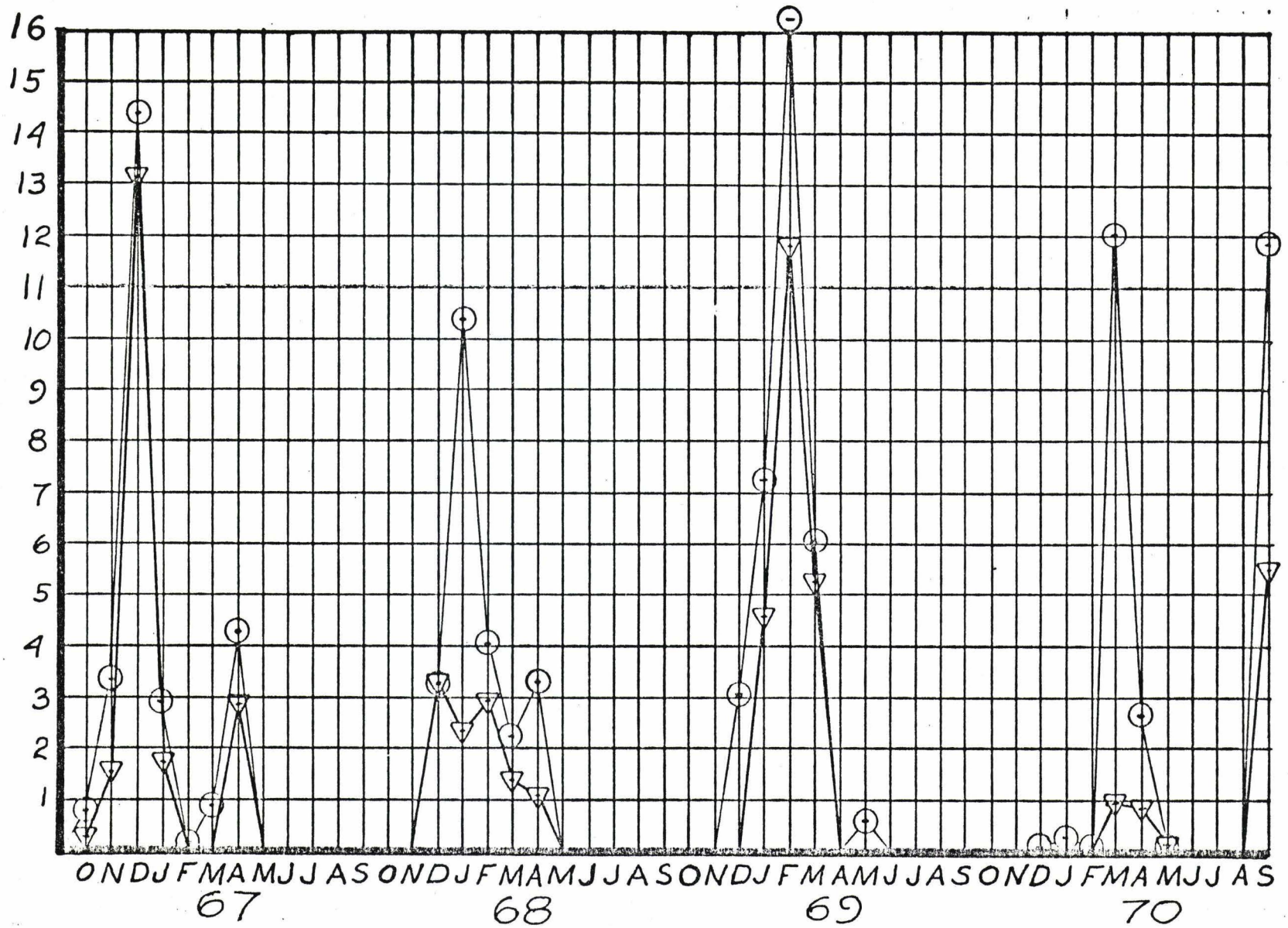
4 Actual Flows vs. Development Level 4 (O)



5 Actual Flows (vs. Development Level 5 (O)



6 Actual Flows) vs. Development Level 6 (O)



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